

ORIGINAL RESEARCH

BIOMECHANICAL DIFFERENCES IN BRAZILIAN JIU-JITSU ATHLETES: THE ROLE OF COMBAT STYLE

Pedro Olavo de Paula Lima, PT, PhD¹Alane Almeida Lima, PT student²Anita Camila Sampaio Coelho, PT student²Yuri Lopes Lima, PT student²Gabriel Peixoto Leão Almeida, PhD student¹Márcio Almeida Bezerra, PhD student¹Rodrigo Ribeiro de Oliveira, PT, PhD¹

ABSTRACT

Background: Brazilian Jiu-Jitsu (BJJ) athletes can be divided into two combat styles: pass fighters (PFs) and guard fighters (GFs). Flexibility of the posterior chain muscles is highly necessary in these athletes, especially in GFs. On the other hand, isometric strength of the trunk extensors is required in PFs. Handgrip strength is important in holding the kimono of the opponent, and symmetrical lower-limb strength is important for the prevention of injuries due to the overload caused by training.

Purpose: The aim of this study was to compare the biomechanical profiles of BJJ athletes with different combat styles using the following outcome measures: flexibility, trunk extensor isometric endurance, postural balance, handgrip isometric endurance and lower-limb muscle strength.

Methods: A cross-sectional study was conducted using 19 GFs and 19 PFs. The sit-and-reach test was used to evaluate the flexibility of the posterior chain muscles. The Biodex Balance System® was used to evaluate balance. A handgrip dynamometer and a dorsal dynamometer were used to evaluate handgrip and trunk extensor endurance, respectively. Quadriceps and hamstring strength were evaluated with an isokinetic dynamometer at 60°/s.

Results: No differences were observed between groups in terms of flexibility, balance, handgrip isometric endurance or quadriceps and hamstring strength; however, PFs (81.33) showed more isometric trunk extension endurance than GFs (68.85) ($p = 0.02$). Both groups had low values for hamstring/quadriceps ratio.

Conclusion: No significant biomechanical differences were observed between PFs and GFs.

Keywords: Jiu-Jitsu, martial arts, muscle strength, postural balance

Level of Evidence: 2b

CORRESPONDING AUTHOR

Pedro Olavo de Paula Lima
Analysis Laboratory of Human Movement.
Rua Alexandre Baraúna, 949, 1º andar.
Rodolfo Teófilo. Fortaleza, Ceará, Brazil
Phone: + 55 85 33668632 Facsimile: + 55 85
33668002
E-mail: pedrolima@ufc.br

¹ Department of Physical Therapy, Federal University of Ceará, Brazil

² League Sports Physical Therapy, Federal University of Ceará, Brazil

INTRODUCTION

Jiu-Jitsu is a martial art that requires a variety of movements, such as flexion, extension, torsion and traction mechanics and center-of-mass displacement.¹ This style of martial art appeared in Brazil after World War I and has undergone several modifications and adaptations, giving rise to Brazilian Jiu-Jitsu (BJJ), a fighting sport that has gained popularity around the world following the rise of the Ultimate Fighting Championships (UFC). The main techniques in BJJ are grappling, projections, transitions, chokes, and submissions^{2,2}.

BJJ athletes can be divided according to their combat styles into pass fighters (PFs) and guard fighters (GFs). The guard position is considered the essence of Jiu-Jitsu. The traditional position is the closed guard (Figure 1A), where the fighter has his/her back in the mat with legs wrapped around opponent, and he/she can take advantage to launch submissions. He/she can also be in a defensive position. Other guard positions have been created during the BJJ history, such as the spider guard (Figure 1B), De

La Riva guard (Figure 1C), and butterfly guard (Figure 1D).³ The PF attempts to pass the guard of his/her opponent in order to score points or secure dominant positioning, while the GF defends the guard and reacts from this position. Some athletes prefer to choose one combat style and training based on the key aspects of that specific style.⁴

BJJ requires certain physical attributes, such as flexibility, postural balance, isometric endurance, and muscle strength.⁵ An appropriate level of flexibility is necessary to allow joint mobility, thus avoiding limitations during the execution of techniques and the learning of specific drills. Athletes who prefer training from various guard positions require more posterior chain flexibility, especially hip flexibility. In contrast, PFs need more strength in the trunk extensors because GFs force them into trunk flexion.

Upper-limb isometric endurance is essential for good performance in BJJ athletes because most techniques require hand-gripping and grappling.⁶ Hand-grip strength is necessary to hold the opponent's

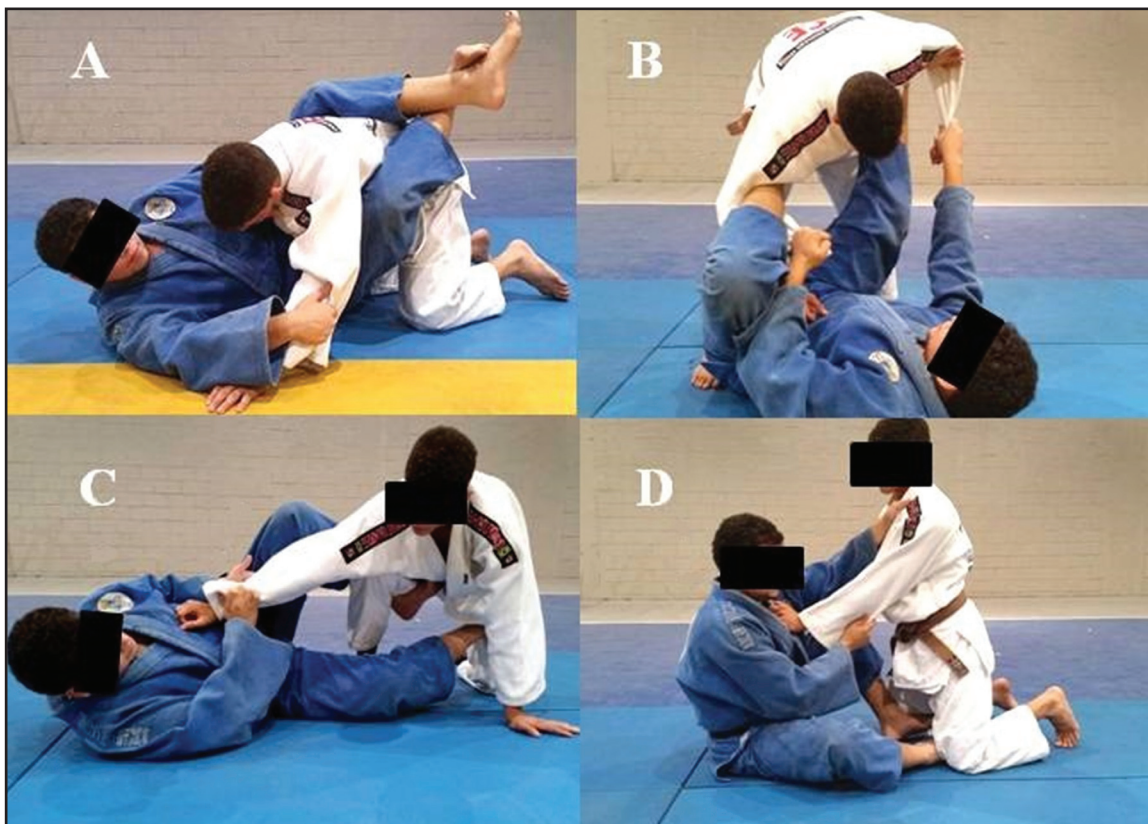


Figure 1. Types of guard position. (A) Closed guard (B) Spider guard (C) De La Riva guard (D) Butterfly guard.

kimono (*i.e.*, uniform),⁷ and successive fights lead to a decrease in handgrip strength⁸ requiring athletes to develop muscle endurance. Symmetrical strength in the lower limbs is essential because BJJ requires long and intense training that causes joint overload, mostly on the knees. Thus, adequate strength of the muscles that contribute to the stability and support of this joint is needed, particularly in the quadriceps and hamstrings because optimal ratios strength in these muscles contribute to a decreased risk of knee injuries.⁹ Dynamic postural stability and control of center of mass displacement are parameters that influence both guard defense and attack techniques.

Some studies regarding physiological demands and aerobic capacity in BJJ athletes have been published.^{10,11} Other studies regarding morphological adaptations (body composition and somatotype) have also been reported in the literature.¹² To date, only one study has compared the biomechanics of combat style in BJJ athletes, and this study evaluated the fundamental movement competency with Functional Movement Screen (FMS®).⁴ No reports have examined strength, flexibility and balance in BJJ athletes.

The purpose of this study was to compare the biomechanical profiles of BJJ athletes with different combat styles (GF vs. PF) using the following outcome measures: flexibility, trunk extensor isometric endurance, postural balance, handgrip isometric endurance and lower-limb muscle strength.

METHODS

Experimental Approach to the Problem

A cross-sectional study was conducted from January to July of 2014. A total of 38 BJJ athletes were divided into two groups for assessment. Nineteen GFs comprised the first group, and 19 PFs comprised the second. The combat style was considered the independent variable, while flexibility, isometric endurance, postural balance, and muscle strength were the dependent variables of the study.

Participants

This study was submitted and approved by the Research Ethics Committee of the Federal University of Ceará (protocol n° 230/2011), and the research participants signed a written informed con-

sent form. The sample size was calculated prior to the testing, using a significant difference of 20% for the flexibility outcome, with an estimated standard deviation of 8 centimeters. A significant difference of 20% was also chosen for the strength of the trunk extensors, with an estimated standard deviation of 36 kgf. A power of 80% and a level of significance of 5% were chosen for this calculation, thus resulting in a sample size of 20 individuals for each group.¹⁰

All the athletes were professionals, over 18 years old and had competed in international-level competitions. The athletes were selected by convenience from a professional team specialized in this sport. Athletes with recent musculoskeletal injuries (*i.e.*, within the last six months) and those who had undergone trauma or orthopaedic surgery in the last 12 months were excluded.

The groups presented similar anthropometric data, ages and practice durations. Only two athletes were left handed, and they were both GFs. Twelve PFs and seven GFs were blue belts (Table 1). The experience in BJJ is ranked according to the color of the belt of the fighters. Blue belts are the least experienced, whereas purple, brown, and black belts are the most experienced levels.¹³

Procedures

A self-report questionnaire was utilized to investigate anthropometric characteristics, motor dominance, injury history and preferred combat style of the athletes. Then, the biomechanical tests were performed.

The athletes were assessed using the following outcome measures: posterior chain muscle flexibility, postural balance, isometric trunk endurance, isometric grip strength, and isokinetic thigh muscle strength. The reliability of the tests used has been analyzed previously.¹⁴⁻¹⁶

The sit-and-reach test was performed in the Wells bench (Sanny®, Brazil) for the assessment of posterior chain muscle flexibility. The subject was positioned in a seated position, with the knees fully extended, the feet touching the bench, and the hands overlapping each other. The protocol consisted of the subject executing three repetitions, and the highest result was used for statistical purposes.¹²

The Biodex Balance System® (BBS)(Biodex Medical Systems, Shirley, NY), which is commonly used to evaluate dynamic postural stability, was utilized for the postural balance assessment. This device measures the degree of inclination over each axis during the tests.¹⁷ The test was performed using the single-leg protocol, and the athletes were positioned with the tested knee at a 10-degree flexion angle and the contralateral limb at a 90-degree flexion angle. The arms were crossed at the level of the chest, and the eyes were directed toward the screen of the device, which was adjusted according to the height of each athlete. At the beginning of the trial, the athlete was instructed to maintain balance. This assessment was repeated three times for each limb, and each repetition lasted twenty seconds, with a 10 second rest interval. The level of stability of the platform of the BBS varied from Level 6 (more stable) to Level 2 (less stable) without any visual feedback to the subject. The Overall Stability Index, Antero-Posterior Stability Index, and Latero-Medial Stability Index (as calculated and provided by the BSS) were assessed.¹⁸

Isometric dynamometry was utilized to assess muscular endurance and strength during the handgrip and trunk extension tests. Both muscle groups were assessed using the Maximum Voluntary Isometric Contraction (MVIC) protocol with three intermittent isometric contractions, as well as a 30-second isometric contraction test. A hand dynamometer (DM-100, Miotec®, Porto Alegre, Brazil) and a back dynamometer (DD-200, Miotec®, Porto Alegre, Brazil) were used. In order to assess handgrip strength, the athlete was asked to position the elbow at a 90° of flexion and squeeze the dynamometer with maximum effort. Three repetitions of five seconds were performed with an interval of 10 seconds between repetitions. In the same position, the athlete was asked to squeeze the dynamometer with maximum effort during 30 seconds for the assessment of endurance. For the evaluation of trunk strength, the athlete was asked to flex the trunk from a standing position, grasp the bar of the back dynamometer with both hands and then lift the bar with maximum effort. Three repetitions of five seconds were performed with an interval of 10 seconds between repetitions. In the same position, the athlete was asked to lift the bar for 30 seconds for the assessment of endurance. The data were sampled at 400 Hz using a Miotool

400 device interface (Miotec®)¹⁹. In order to evaluate muscle strength was recorded the peak force and to evaluate muscle endurance was recorded the average force during each trial.

The assessment of the quadriceps femoris (Q) and hamstrings (H) was performed using a Biodex® (Biodex Medical Systems, Shirley, NY) isokinetic dynamometer. Athletes warmed-up on a stationary bicycle for five minutes. The seat was adjusted so that the hip would remain at an 85-degree flexion angle, and the axis of the device was aligned with the lateral intercondylar notch. Next, the subjects were positioned in the dynamometer with belts fastened at the torso, abdomen, and tested thigh in order to prevent undesired movements. The lever arm of the device was placed 20 mm above the medial malleolus. The selected protocol consisted of concentric contractions at 60°/s for five repetitions.²⁰ The device was calibrated for each subject, starting from a fully flexed knee position and ending in a fully extended knee position, whereas the reference point was a 90-degree knee flexion angle. The lower limb was weighed for standardization purposes. After the initial procedures, the subject was instructed to perform five flexion and extension movements at a submaximal intensity in order to finish the warm-up and familiarization. To compare the groups, it was used the following variables: the symmetry index of strength between limbs and the agonist/antagonist ratio.

Statistical Analyses

SPSS 17.0 was used with a significance level of 5%. The data distribution was analyzed with the Kolmogorov-Smirnov test. The independent t-test and chi-square test were utilized to compare the groups.

RESULTS

The groups were homogeneous regarding weight, height, BMI, and duration of sports practice (Table 1). No athletes were excluded from the initial sample.

There were no significant differences between the groups in terms of flexibility ($p=0.089$) (Table 1). However, a difference was observed in the isometric endurance of the trunk extensors ($p=0.02$); the PFs showed higher values. No statistical differences were observed for peak isometric handgrip strength and trunk extension (Table 2), postural stability (Table 3), or isokinetic variables ($p > 0.05$) (Table 4).

Table 1. *Sample characteristics*

Variable	PF	GF
Age (years)	23.2±15.6 [†]	22.58±5.4 [†]
Weight (kg)	83.26±6.9 [†]	77.53±11.9 [†]
Height (m)	1.73±0.05 [†]	1.74±0.1 [†]
Time of Practice (years)	5.20±4.2 [†]	6.66±3.9 [†]
Posterior Flexibility (cm)	34.84±7.4 [†]	36.47±11.4 [†]
Dominance	Right Left	19 (100%) 0 17 (89.5%) 02 (10.5%)
Graduation (Belt color)	White Blue Purple Brown Black Total	0 12 (63.2%) 03 (15.8%) 01 (5.3%) 03 (15.8%) 19 (100%) 01 (5.3%) 07 (36.8%) 06 (31.6%) 03 (15.8%) 02 (10.5%) 19 (100%)

[†] mean ± standard deviation. PF: pass fighter; GF: guard fighter.

Table 2. *Comparison of balance variables between the groups*

Variable	Group	Mean ± SD	p
Overall Stability DL	GF	6.65±3.26°	0.06
	PF	5.12±1.59°	
Overall Stability non-DL	GF	6.34±3.37°	0.15
	PF	5.01±1.51°	
Antero-Posterior Stability DL	GF	4.04±2.40°	0.11
	PF	3.01±1.02°	
Antero-Posterior Stability non-DL	GF	3.51±1.94°	0.55
	PF	3.20±1.08°	
Medial-Lateral Stability DL	GF	4.35±2.74°	0.06
	PF	3.29±1.06°	
Medial-Lateral Stability non-DL	GF	4.57±2.94°	0.10
	PF	3.20±1.70°	

PF: pass fighter; GF: guard fighter; DL: Dominant limb; Non-DL: Non-Dominant Limb. SD: standard deviation.

Table 3. *Comparison of variables of isometric muscle strength between groups (reported in Kilogram)*

Variable	Group	Mean ± SD	p-value
Peak isometric handgrip strength DL	GF	56.64±20.73	0.96
	PF	56.31±20.99	
Peak isometric handgrip strength Non-DL	GF	55.33±19.74	0.80
	PF	53.61±20.49	
Handgrip isometric endurance DL	GF	32.58±10.67	0.65
	PF	34.54±15.44	
Handgrip isometric endurance Non-DL	GF	32.32±10.78	0.91
	PF	32.78±13.97	
Peak trunk extension isometric strength	GF	116.08±22.61	0.39
	PF	123.61±30.70	
Trunk extension isometric endurance	GF	68.85±12.09	0.02*
	PF	81.33±19.13	

* Significant at 5% level. PF: pass fighter; GF: guard fighter; DL: Dominant limb; Non-DL: Non-Dominant Limb. SD: standard deviation.

Table 4. Comparison of the isokinetic variables between groups

Variable	Group	Mean ± SD	p-value
Peak Torque of Quadriceps DL	GF	279.62±40.57 N.m/Kg	0.19
	PF	294.50±26.42 N.m/Kg	
Peak Torque of Quadriceps Non-DL	GF	287.54±44.62 N.m/Kg	0.17
	PF	278.24±38.73 N.m/Kg	
Peak Torque of Hamstrings DL	GF	140.82±24.82 N.m/Kg	0.40
	PF	147.03±20.31 N.m/Kg	
Peak Torque of Hamstrings Non-DL	GF	146.57±33.23 N.m/Kg	0.12
	PF	132.47±20.30 N.m/Kg	
H/Q ratio DL	GF	50.67±7.84 %	0.75
	PF	49.98±5.80 %	
H/Q ratio Non-DL	GF	51.36±10.60 %	0.70
	PF	46.07±6.09 %	

PF: pass fighter; GF: guard fighter; DL: Dominant limb; Non-DL: Non-Dominant Limb; H: hamstrings, Q: quadriceps. SD: standard deviation.

DISCUSSION

In general, biomechanical differences among BJJ athletes with different combat styles were not observed. The only difference found was that PFs showed more isometric trunk extension endurance than GFs, which is plausible considering the movements involved in the most prevalent techniques of this combat style.

Flexibility

Most of the athletes showed higher flexibility levels than the average population in the same age level according to the standard levels proposed by the Canadian Standardized Test of Fitness (CSTF), which is also reported in the scientific literature,¹¹ as being the way of knowledge that involves methodic and organized investigation for its operations in searching results that confirm or annul hypothetical propositions.

There were no differences in flexibility between the groups in this study. The authors hypothesized that GFs would have higher flexibility in the posterior chain muscles, such as: spinal paraspinals, hamstrings and calves muscles. Posterior chain flexibility is extremely important for Jiu-Jitsu athletes, particularly GFs. It was hypothesized that GFs would present more flexibility because they spend most time of the fight in supine position with hips flexed trying to create space for a submission³. However, it must be noted that Jiu-Jitsu is a dynamic sport and that

even an athlete with a preferred combat style must sometimes resort to other combat strategies, so that GFs occasionally need to fight in standing position, which is common for PFs.³

Isometric muscle endurance

The fact that PFs exhibit higher trunk extension isometric muscle endurance than GFs was the only statistically significant difference found, which is comprehensible if the biomechanics of the techniques that are most prevalent in this combat style are considered. The authors purpose that PFs require extreme trunk extensor muscle endurance because GFs spend most of the fight time trying to pull PFs to the ground in submission attempts. This difference is clinically important because a Jiu-Jitsu match can last up to 15-25 minutes.

No studies comparing trunk extensor muscle strength in PFs and GFs were found. However, a descriptive study of Jiu-Jitsu athletes concluded that these athletes exhibited higher trunk extensor isometric muscle strength as compared with judokas.¹¹ These differences between athletes who utilize different fighting styles was not assessed in the current study, as the current study compared fighting styles within Jiu-Jitsu instead of comparing with other fighting modalities.

No significant difference was found between the groups regarding isometric variables for muscular endurance and peak handgrip strength. However,

one study²¹ demonstrated a significant difference in relation to handgrip strength in the intermittent isometric contractions test. This test consisted of performing three repetitions of a five-second handgrip with an interval of one minute between repetitions. The athlete was oriented to keep the shoulder adducted alongside the body, with the elbow in 90° of flexion and forearm and wrist in neutral position. The athlete was in a seated position with hips and knees in 90° of flexion and feet on the ground. It was observed that the Jiu-Jitsu athletes showed greater strength in the left hand, although hand dominance was not considered in this study. It is important to consider that study compared athletes with sedentary subjects, while a comparison between two groups of athletes with similar levels of strength and isometric muscular endurance was performed in the current study, with no significant differences between the groups being expected. Another study conducted by Vidal Andreato et al⁸ found a significant difference in handgrip endurance when athletes were wearing the kimono. In addition, the authors found a decrease in maximum isometric handgrip strength in both the dominant and non-dominant extremities after fights.⁸

Jiu-Jitsu athletes exhibit higher handgrip strength values in the dominant hand when compared to rowers, aikido athletes, and non-athletes, as well as higher handgrip strength values in the non-dominant hand when compared to aikido athletes and non-athletes ($p < 0.05$).²¹ These results seem to be reasonable because Jiu-Jitsu is a sport that requires holding maneuvers, so that repeatedly demanding handgrip strength.²¹ The results of the current study did not show any significant differences between groups, likely because the comparison was made between athletes of the same sport, and as already mentioned, the development of muscle strength and endurance in both combat styles is necessary.

Postural Stability

The athletes in the current study had no significant differences in dynamic postural stability. These results were expected because these athletes participated in the same sport and all had similar balance demands. No previous studies analyzing the dynamic postural stability of Jiu-Jitsu athletes were found. To date, only one study verified differences

in postural control involving martial artists. This study found that black belt martial artists presented greater postural control than sedentary people.²²

Due to a lack of evidence, similarities between judo and Jiu-Jitsu were considered for this discussion. Judokas have better dynamic balance than non-athletes,²³ while amateur judokas and dancers have better stability with open eyes than high-performance judokas, professional dancers and controls. For stability with eyes closed, only the judokas presented good results.²⁴ However, another study using the BBS to evaluate balance did not find significant differences between judokas and non-athletes, despite the fact that they mentioned static and dynamic postural balance as crucial for defense and attack.¹⁸

Isokinetic Muscle Strength

No studies analyzing the isokinetic muscle strength of the knee extensors and flexors in Jiu-Jitsu athletes were found. One study aimed to assess the strength of the knee extensors and flexors in judokas. When assessed using an isokinetic dynamometer at 90°/s, 180°/s, and 240°/s, judokas demonstrated a higher peak torque for the extensors and flexors of the supporting leg than those of the attacking leg ($p < 0.05$). The agonist/antagonist ratio was normal in both limbs in the aforementioned velocities.²⁵ In the current study, the athletes of both groups exhibited lower results than the normative values for the agonist/antagonist ratio (*i.e.*, 60% in slow velocities: 60°/s to 180°/s – and 80% in high velocities: 300°/s to 450°/s).²⁶ These results suggest that both groups had muscular imbalances considering agonist/antagonist ratio, demonstrating hamstrings deficits. Regarding the peak torque of the knee extensors and flexors, no significant differences among athletes with distinctive combat styles were observed.

Some authors have attempted to compare various styles of combat and verify the anthropometric and morphological characteristics of PFs and GFs. A study conducted by Baéz¹¹ noted that PFs exhibit more mesomorphic bodies than GFs (ectomorphic), because PFs must assume more positions that require muscle strength during the fight, such as, staying over the knees to pull the opponent. PFs also need more strength due to be continuously trying to pass the guard of the opponent.²¹ A study performed

by Boscolo⁴ did not find differences in joint mobility, stability, proprioception, strength and flexibility when comparing different combat styles.

The study design was a limiting factor because the cause and effect relationships were evaluated at same time. Therefore, authors suggest conducting a prospective cohort study to examine the causality between combat style and biomechanical variables. Another limitation is the fact that the assessment was conducted in only one professional team of BJJ, reinforcing that findings must be interpreted with caution because findings may be unique to the training and performance of that specific team.

CONCLUSION

No significant biomechanical differences were found between BJJ athletes with two different combat styles. PFs exhibited greater trunk extensor muscle endurance than GFs, while all other parameters were not different between groups. Even given a preferred combat style, BJJ athletes must practice and be prepared for a variety of situations, and this may be the reason there are no substantial biomechanical differences between athletes.

Clinical Relevance

In general, athletes and coaches choose a fighting style based on the biomechanical characteristics of the individual because they believe that physical factors are crucial in choosing the fighting style that will be developed by each athlete. However, this study showed no differences between athletes with a preference for the guard style and those with a preference for the pass style. Therefore, the choice of fighting style need not be influenced by these factors.

What is known about the subject

There are few studies comparing Brazilian Jiu-Jitsu athletes with different fighting styles, and most are of low methodological quality. The current evidence indicates that there may be physiological, morphological, and functional differences between these athletes. However, no study to date has compared the biomechanical characteristics of these athletes.

What this study adds to existing knowledge

In general, no significant biomechanical differences were found between BJJ athletes with the two

above-mentioned combat styles. The specific training required for a given fighting style is not associated with biomechanical differences, regardless of the athlete's preference.

REFERENCES

1. Rigatto PC. *Efeito do treinamento de potencia muscular sobre o aprimoramento do perfil metabólico e do rendimento no randori em praticantes de jiu-jitsu (Trabalho de Conclusão de Curso)*. Bauru, São Paulo, Universidade Estadual Paulista; 2008.
2. Takahashi R. Plyometrics: Power training for judo: Plyometric training with medicine balls. *Strength Cond J*. 1992;14(2):66-71.
3. Spencer DC. From many masters to many Students: YouTube, Brazilian Jiu Jitsu, and communities of practice. *Jomec Journal*. 2016(5).
4. Boscolo DVF, Foster D, Arruda A. Functional Movement Screening performance of Brazilian jiu-jitsu athletes from Brazil: differences considering practice time and combat style. *J Strength Cond Res*. 2016; 30(8):2341-7.
5. Soares WD, Santos RS, Almeida FN, *et al*. Determinação dos níveis de flexibilidade em atletas de Karatê e jiu-jitsu. *Motricidade*. 2005; 1(4):246-252.
6. Costa EC, dos Santos CM, Prestes J, *et al*. Efeito agudo do alongamento estático no desempenho de força de atletas de jiu-jitsu no supino horizontal. *F&P J*. 2009;8(3):212-217.
7. Borges Junior NG, Domenech SC, da Silva ACK, *et al*. Estudo comparativo da força de preensão isométrica máxima em diferentes modalidades esportivas. *Rev Bras Cineantropom Desempenho Hum*. 2009;11(3):292-298.
8. Vidal Andreato L, Julio UF, Panissa VLG, *et al*. Brazilian jiu-jitsu simulated competition, Part II: Physical performance, time-motion, technical-tactical analyses and perceptual responses. *J Strength Cond Res* 2015;29(7).
9. de Assis MMV, Gomes MI, Carvalho EMS. Avaliação isocinética de quadríceps e ísquios-tibiais nos atletas de jiu-jitsu. *Rev Bras. Promoç Saúde*. 2012;18(2):85-89.
10. Vidal Andreato L, Franzói de Moraes SM, Del Conti Esteves JV, *et al*. Physiological responses and rate of perceived exertion in Brazilian jiu-jitsu athletes. *Kineziologija*. 2012a;44(2):173-181.
11. Vidal Andreato L, Franzói de Moraes SM, de Moraes Gomes TL, *et al*. Estimated aerobic power, muscular strength and flexibility in elite Brazilian Jiu-Jitsu athletes. *Science & Sports*. 2011;26(6):329-337.
12. Baéz EI, Franchini E, Ramírez-Campillo R, *et al*. Anthropometric characteristics of top-class brazilian

-
- jiu jitsu athletes: Role of fighting style. *Int J Morphol*. 2014;32(3):1043-1050.
13. Kreiswirth EM, Myer GD, Rauh MJ. Incidence of injury among male Brazilian jiu-jitsu fighters at the World Jiu-Jitsu No-Gi Championship 2009. *J Athl Train*. 2014;49(1):89.
 14. Cacheupe WJ, Shifflett B, Kahanov L, et al. Reliability of biodex balance system measures. *Meas Phys Educ Exerc Sci*. 2001;5(2):97-108.
 15. Drouin JM, Valovich-mcLeod TC, Shultz SJ, et al. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol*. 2004;91(1):22-29.
 16. Wells KF, Dillon EK. The sit and reach—a test of back and leg flexibility. *Res Quart. Am Assoc Health Phys Educ Rec*. 1952;23(1):115-118.
 17. Arnold BL, Schmitz RJ. Examination of balance measures produced by the Biodex Stability System. *J Athl Train*. 1998;33(4):323.
 18. Alonso AC, Brech GC, Moscoli F. Estudo comparativo do equilíbrio postural entre atletas de judô e indivíduos sedentários. *Brazilian J Biomech*. 2009;9(17):130-137.
 19. Cadore EL, Pinto RS, Alberton CL, et al. Neuromuscular economy, strength, and endurance in healthy elderly men. *J Str Condit Res*. 2011;25(4):997-1003.
 20. Terreri ASA, Ambrósio MA, Pedrinelli A, et al. Isokinetic assessment of the flexor-extensor balance of the knee in athletes with total rupture of the anterior cruciate ligament. *Revista do Hospital das Clínicas*. 1999;54(2):35-38.
 21. Oliveira M, Moreira D, Godoy JRPd, et al. Avaliação da força de preensão palmar em atletas de jiu-jitsu de nível competitivo. *Revista Brasileira de Ciência e Movimento*. 2006;14(3):63-70.
 22. Krampe RT, Smolders C, Doumas M. Leisure sports and postural control: Can a black belt protect your balance from aging? *Psych Aging*. 2014;29(1):95.
 23. Yoshitomi SK, Tanaka C, Duarte M, et al. Postural responses to unexpected external perturbation in judoists of different ability levels. *Revista Brasileira de Medicina do Esporte*. 2006;12(3):159-163.
 24. Perrin P, Devitterne D, Hugel F, et al. Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait & posture*. 2002;15(2):187-194.
 25. Ghrairi M, Hammouda O, Malliaropoulos N. Muscular strength profile in Tunisian male national judo team. *Musc Lig Tend J*. 2014;4(2):149.
 26. Zabka FF, Valente HG, Pacheco AM. Avaliação isocinética dos músculos extensores e flexores de joelho em jogadores de futebol profissional. *Revista Brasileira de Medicina do Esporte*. 2011;17(3):189-192.
-